Detection of Micro-Cracks in the HP Turbine Blades Using Phased Array and Radiography Techniques and Enhancement of Radiographic Images by Image Processing


* NIT, Trichy, ** NDED, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, *** IIT, Madras.

Abstract

The HP (high pressure) turbine blades were received from the 220 MW nuclear power plant (MAPS, NPCIL). The blades were in-service for 33,102 hr within and above steam temperature (250°C). These blades were found to be failed. These blades were used for the present investigation. An attempt is made to find micro cracks in turbine blades using NDE techniques. Turbine blades are known to fail due to tempered martensite embrittlement, fatigue, fretting, high temperature creep, age hardening, fir-tree design, high residual stresses etc. Detailed failure investigation was carried out using various NDE techniques like Phased array technique, Radiography and Image enhancement using image processing. By using phased array technique, length as well as depth of the crack has been identified. Length of the crack is 22mm and depth was varying from 11mm to 15mm.

The crack that was identified earlier by phased array technique is confirmed by X-ray Radiography. The Radiography images were digitized and then enhanced using image processing techniques. For image enhancement, band-pass filter was applied on the radiographic images since this filter can perform simultaneous dynamic range compression and contrast enhancement. The present methodology facilitates the detection and quantification of defects such as micro-cracks with better contrast and accuracy. This paper highlights the experimental challenges in phased array technique and Radiography of turbine blades and also how application of image enhancement and processing aids in improving the reliability of defect detection.

Keywords: HP turbine blades, Nuclear Power Plant, Phased array technique, Radiography, image enhancement and processing, micro cracks.

1. Introduction

Failure of the turbine blades was one of the challenges addressed with the help of BHEL by modifications of LP stage-5 blade, shroud modifications etc., and based on its success, the same technique was used for other plants to sort out inherent problems. Grid-induced Outages Grid disturbance induced outages were overcome by house load schemes and in one-month viz., May 1998, as many as 150 house load operations took place and units operated withstanding these transients. Healthiness of the control system and other equipment to withstand external grid transients was remarkable. The sharp corner in the root section of the blade causes the blade to crack. Failure of the turbine blades was one of the challenges addressed with the help of BHEL by modifications of HP stage-5 blade, shroud modifications etc., and based on its success, the same technique was used for other plants to sort out inherent problems. The material used was 12Cr-Mo martensitic steel, which is a very high temperature resistant material. The microstructure was observed was tempered martensitic structure. These turbine blades were collected from Madras Atomic Power Station (MAPS) for analysis. These blades were found to be failed. These blades were used for the present investigation of defects using ultrasonic phased array and X-ray radiography techniques. Turbine blades are known to fail due to tempered martensite embrittlement, fatigue, fretting, high temperature creep, age hardening, fir-tree design, high residual stresses etc [1-5].

2. Experimental procedure

Chemical composition of turbine blade is shown in the following Table 1. Figures 1 and 2 show typical photograph of the turbine blade and fir-tree region of the turbine blade respectively. This Fir-tree design of the turbine blades is very complex. The HP (high pressure) turbine blades were

![Fig. 1 : Typical photograph of the turbine blade](image-url)
received from the 220 MW nuclear power plants (MAPS, NPCIL). The blades were in-service for 33,102 hrs within and above steam temperature (250°C) [1].

Table 1 : Chemical compositions of the turbine blade:

<table>
<thead>
<tr>
<th>Element</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur</td>
<td>0.019 to 0.03</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.019 to 0.028</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.20 to 0.24</td>
</tr>
<tr>
<td>Chromium</td>
<td>12.8 + 1.2</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.45 to 0.54</td>
</tr>
<tr>
<td>Silicone</td>
<td>0.30 to 0.43</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.40 to 0.52</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.05</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.1 to 0.13</td>
</tr>
<tr>
<td>Iron</td>
<td>Balance</td>
</tr>
</tbody>
</table>

2.1 Phased array technique [6, 7]

Investigation of defects using Phased array technique was done at NDT Centre, Indian Institute of Technology, Madras. Seven blades were selected for this study. Omni Scan MX PA is Phased array semi automated equipment as shown in the Fig 3. Omni scan has the ability to give all scans and also the combination (A, B, C, S-scans). Images of three scans can be obtained in single scanning processes. Experiments are done on the fir-tree design of the turbine blades. The fir-tree design of the turbine blades is very complex. Hence the results from different locations are to be compared carefully for estimation of defects. The experiments were carried out at different locations.

Omni scan has ability to give all scans and also the combination (A, B, C, S - scan)

- Initial setup should be made
- Type of material under scanning
- Type of probe used (normal or angle)
- Type of scan (linear, linear at 0 deg, angular)
- Gain setup
- Range setting
- Type of display needed (A, B, C, S-scan)

Probe Details of Phased Array Probe

The probe used in experiment in which crystals are arranged linearly as shown in Fig. 4 and Table 2 shows the Specifications of phased array probe used for the experiments

Table 2 : Specifications of phased array probe

<table>
<thead>
<tr>
<th>Model number</th>
<th>5L64-C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Element quantity</td>
<td>64</td>
</tr>
<tr>
<td>No of elements activated</td>
<td>1-16, 2-17, 3-18...49-64,</td>
</tr>
<tr>
<td>probe</td>
<td>normal phased array</td>
</tr>
<tr>
<td>Element Pitch</td>
<td>0.620mm</td>
</tr>
</tbody>
</table>

2.2 Radiography technique [8,9]

Radiography is one of the oldest NDE techniques and is widely used for detection of volumetric defects such as voids and porosity. It is based on the principle of differential absorption of penetrating radiation. The amount of radiation absorbed depends upon the density, thickness and composition of the material.

After identifying the crack using the Phased array technique, radiography was used to confirm the crack in the fir-tree design. Radiography was carried out using a 450 kV
3. Results and discussions

3.1 Phased Array technique

Images were obtained using phased array technique at various locations. Images of defect free and defective turbine blades at third location with same direction are illustrated in Fig 4, 5 and Fig 6 shows the back wall image for 11mm thick section of defect free Turbine blade where as Fig 5 shows the crack indication at the same region of inspecting sample 1 and compares with the reference indication which revealed that there was a crack near to the back wall.

The crack was identified in one turbine blade using Phased array technique. There are no defects in the other turbine blades. The length as well as depth of the crack has been determined using this technique. (Fig. 6). No back wall at 21mm is obtained because all the energy is scattered by crack, no energy is transmitted through crack to hit back wall. Length of the crack is 22mm and depth was varying from 11mm to15mm is as shown in Fig 6.

Table 3: Radiographic Parameters

<table>
<thead>
<tr>
<th>X-ray machine</th>
<th>450kV Baltograph X-ray machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage used</td>
<td>240kV</td>
</tr>
<tr>
<td>Exposure</td>
<td>40mA.mins</td>
</tr>
<tr>
<td>Source to object Distance</td>
<td>1000mm</td>
</tr>
<tr>
<td>Film</td>
<td>Kodak DR 50</td>
</tr>
<tr>
<td>Density in the ROI</td>
<td>2.0 – 4.0</td>
</tr>
<tr>
<td>Processing</td>
<td>Manual, Standard</td>
</tr>
</tbody>
</table>
It is also possible to treat irrelevant scene details as if they were image noise (e.g. surface reflectance textures). The characteristics of noise depend on their source, as does the operator which best reduces their effects. Hence, it is desirable to remove all such noise before interpretation. Also, radiographic images are often of low contrast and lack sharpness. On many occasions, a complex background makes radiographic images difficult to interpret. Therefore, images are required to be modified in such a way as to enhance diagnostically relevant image content. Image enhancement is described as manipulation of a digital image that suppresses irrelevant surroundings and improves visibility of the structural features of interest. The enhanced operation does not increase the dynamic range of the chosen features so that they can be detected easily. Several digital filters are used for such purposes. Selection of image enhancement filters depends on the type of information to be extracted from the original image.

3.2 Radiography technique

Figure 7 shows the digitized radiography image of turbine blade. Crack is seen in the radiograph and it is marked by blue circle (Fig.7) The radiographic image contains some noises that are undesired signals in an image.

Noise, in its broadest definition, encompasses any 'unwanted signal in a data set'. The underlying assumption in this definition is that image data contains a 'true signal' and additional signals of no interest to the task in hand. It is evident that such a broad definition implies the relativity, task-dependence, and often subjectivity of the noise. Noises are random background events, which have to be dealt with in every system processing real signals. They are not part of the ideal signal and may be caused by a wide range of sources, e.g. variations in the detector sensitivity, environmental variations, the discrete nature of radiation, transmission or quantization errors, etc. It is also possible to treat irrelevant scene details as if they were image noise (e.g. surface reflectance textures). The characteristics of noise depend on their source, as does the operator which best reduces their effects.

Hence, it is desirable to remove all such noise before interpretation. Also, radiographic images are often of low contrast and lack sharpness. On many occasions, a complex background makes radiographic images difficult to interpret. Therefore, images are required to be modified in such a way as to enhance diagnostically relevant image content. Image enhancement is described as manipulation of a digital image that suppresses irrelevant surroundings and improves visibility of the structural features of interest. The enhanced operation does not increase the dynamic range of the chosen features so that they can be detected easily. Several digital filters are used for such purposes. Selection of image enhancement filters depends on the type of information to be extracted from the original image.

![Fig. 6: Crack at the depth of 11-15mm with a length of 22mm](image6)

![Fig. 7: Digitized radiography image of HP turbine blade](image7)

![Fig. 8: Enhanced Radiographic image of turbine blade](image8)
3.3 Image Enhancement [10-13].

The radiograph was digitized and then enhanced and processing using image processing software. For image enhancement, band-pass filter was applied on the radiographic image since this filter can perform simultaneous dynamic range compression and contrast enhancement. Image enhancement and processing indicated the presence of fine cracks in the proximity of fir tree design. Fig 8, 9 shows the enhanced image of turbine blade after image processing. Image enhancement techniques are used to improve an image, where “improve” is some times defined objectively to increase the signal-to-noise ratio.

Figure 10 shows a low-contrast image with its histogram shows the distribution of intensities in a gray scale image.

Adjust image and its histogram

- Intensity adjustment is an image enhancement technique that maps an intensity values to a new range.

The Fig.11 displays the adjusted image and its histogram. Notice the increased contrast in the image and that the histogram now fills the entire range.

**Image Enhancement using band pass filter**

Figure 12 shows the micro cracks at proximity of fir tree design, for image enhancement, band-pass filter was applied on the radiographic image. Image enhancement and processing indicated the presence of fine cracks in the proximity of fir tree design.

4. Conclusions

Seven turbine blades were analyzed for crack identification. Micro-cracks were identified in one turbine blade using Phased array technique. The length as well as depth of the crack was determined using phased array technique. Length of the crack is 22 mm and depth was varying from 11 mm to 15 mm. X-ray Radiography confirmed the crack that was identified earlier by phased array technique. There was no other crack, voids, and flaw in the volume of the material. The crack was shown in the root section (fir-tree design) of the turbine blade. The radiographs were digitized and then Radiographic images were enhanced using band pass filter. Image enhancement and processing indicated the presence of fine cracks in the proximity of fir tree design.
Acknowledgements

We are extremely grateful to Dr. Baldev Raj, Director, IGCAR for the constant support and encouragement. Authors are thankful to Dr. T. Jayakumar, Head, NDED for the support.

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